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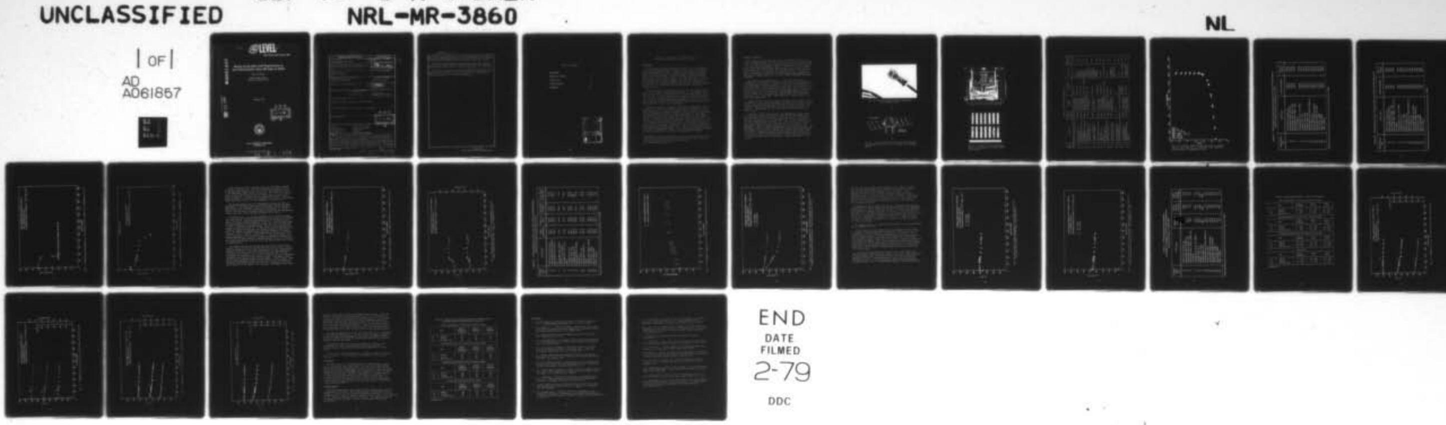

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Results of the Solar Cell Experiments on the NTS-2 Satellite After 223 Days in Orbit

Delores H. Walker

Radiation Effects Branch
Radiation Technology Division

September 1978

NAVAL RESEARCH LABORATORY
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Results after 223 days in orbit of the solar cell experiments aboard the NTS-2 satellite are presented. The objective of the solar cell experiment, consisting of fifteen (15) separate experiments of five cells each, is to evaluate the performance of state-of-the-art solar cells in the space environment. These experiments will answer questions that have arisen from the previous NTS-1 solar cell experiments such as: the need for ultraviolet rejection filters in space solar cell systems, space qualification of (continued)

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electrostatic bonding techniques for solar cell coverslides, and the improved efficiency to be realized from the use of textured cell surfaces. In addition, a gallium arsenide (GaAlAs/GaAs) solar cell module is being flight tested.

The average value of I_{sc} measured in space on the first day of exposure agreed with solar simulator values to within 1.41 + 0.99 percent. The agreement between V_{oc} in space with solar simulator values was 1.24 + 1.08 percent.

After 223 days in orbit, the loss in power ranged from 4.6 percent to 46.5 percent with the exception of the Solarex "low-cost space cell" which became open-circuited on the 69th day. Results are given of the changes in the photovoltaic parameters of each of the experiments.

TABLE OF CONTENTS

Results of the Solar Cell Experiments on the NTS-2 Satellite After 223 Days in Orbit*

Background

The Navigation Technology Satellite-Two (NTS-2) is the second in a series of developmental satellites that are forerunners of the NAVSTAR Global Positioning System (GPS). NAVSTAR GPS is being developed as a group of satellites that will use passive ranging techniques combined with highly accurate clocks to provide extremely accurate navigation capability to ships, aircraft, ground forces and other users 24 hours a day, worldwide in any kind of weather. The GPS satellites will occupy various positions in orbit affording three-dimensional navigational information, i.e., longitude, latitude, and altitude. NTS-2 was launched 23 June 1977 into a twelve-hour circular orbit 20,192 km high at an inclination of 63°.

The GPS satellites are powered by solar cells. The radiation which solar cells encounter in space produces defects in the semiconductor materials that cause a reduction in the solar cell power output. Therefore, in order to predict the expected lifetime of a satellite mission, it is necessary to know quantitatively the effects of radiation on solar cells in space. Although numerous measurements of solar cells have been made in the laboratory,[1-10] it is more significant to observe solar cell degradation in the actual space environment.

There are fifteen (15) solar cell experiments aboard NTS-2. These experiments are designed to compare initial space performance with pre-launch ground data, to measure degradation rates throughout the flight, and to determine the radiation resistance of several types of experimental and advanced design solar cells. These experiments will also answer questions that have arisen from the NTS-1[11-13] solar cell experiments, such as: the need for ultraviolet rejection filters in space solar cell systems, space qualification of electrostatic bonding techniques for solar cell coverslips and the improved efficiency to be realized from the use of textured cell surfaces. In addition, a gallium arsenide (GaAlAs/GaAs) solar cell module is being flight tested. Each of the fifteen separate experiments consists of an array of five 2 cm x 2 cm state-of-the-art solar cells with all experiments linked to an electronics package which measures the entire photovoltaic I-V curve of each experiment in sequence.

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*This work is partially supported by the Space Applications Branch of the Naval Research Laboratory, by the Air Force Aero Propulsion Laboratory, and by the Space and Missile Systems Organization.

Note: Manuscript submitted August 22, 1978.

Summary of Progress

This report covers the analysis of data from the NTS-2 solar cell flight experiments through its first 223 days in orbit. This period began 7 July 1977 when the solar paddles were deployed, exposing the solar cells to the total space environment. Figure 1(a) shows the solar cell paddles as they were folded during launch and Fig. 1(b) shows the sun-oriented paddles after they were deployed. The placement of the solar cell experiments on the body of the satellite is shown in Fig. 2(a). A close-up view of the modules as mounted on the two one-quarter inch aluminum honeycomb panels is shown in Fig. 2(b). A list of these experiments is given in Table I.

The current-voltage characteristics of the solar cell arrays are telemetered in real time as the satellite passes over the tracking station at Blossom Point, Maryland. A typical I-V curve after corrections for solar aspect angle, solar intensity (day-of-the-year) and corrected to 50°C is shown in Fig. 3. The average value of the short-circuit current (I_{sc}) measured in space on the first day of exposure agreed with the solar simulation values to 1.41 $\pm$ 0.99 percent. The agreement between the open-circuit voltage (V_{oc}) on initial space exposure and the solar simulator values was 1.24 $\pm$ 2.02 percent. These results are shown in Table II and Table III, respectively.

During the first 223 days in orbit, Experiment #8, the Solarex "low-cost space cell" has ceased functioning. Fortunately this failure occurred during a time while data were being recorded, allowing the abrupt manner in which it failed to be observed. The data indicate an open-circuited condition. The suddenness of the failure which occurred on day 69 is shown in Fig. 4.

Following a large and rapid drop in the maximum power (P_{max}) output of the Solarex vertical junction cell around day 185, as shown in Fig. 5, the power output of the cells seems to have stabilized. The vertical junction cell started out as an efficient solar cell with a beginning-of-life (BOL) maximum power of 63 mW at 50°C. The vertical junction cell is not yet a production type cell; the data indicate the need for further development. When the vertical junction solar cell reaches its full potential, it will be a radiation hardened cell with high efficiency. The performance of this cell will continue to be studied with great interest. The decrease in P_{max} output of the vertical junction cell by day 223 was 46.5 percent. Results of thermal testing presently under investigation at the Air Force Aero Propulsion Laboratory indicate that the large drop in P_{max} we have observed is probably due to thermal degradation of the contact.

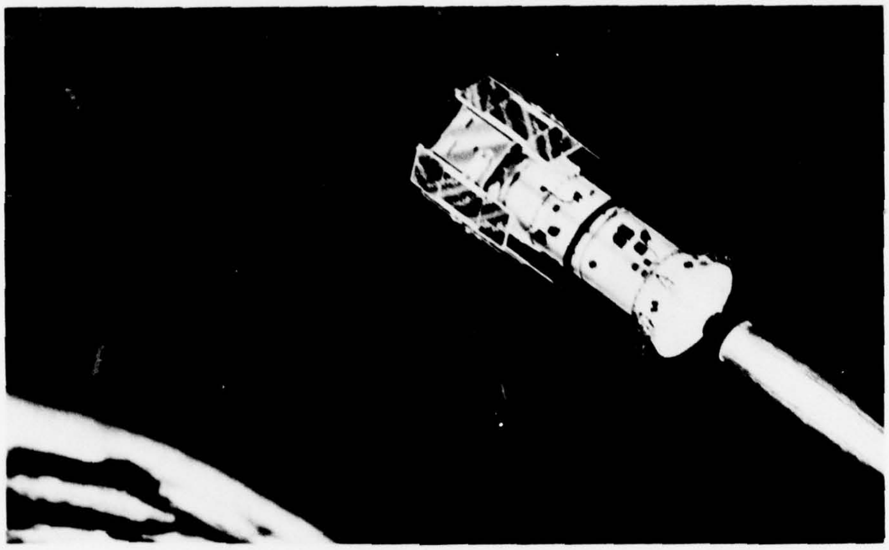

Fig. 1a - The NTS-2 satellite with solar paddles folded during launch

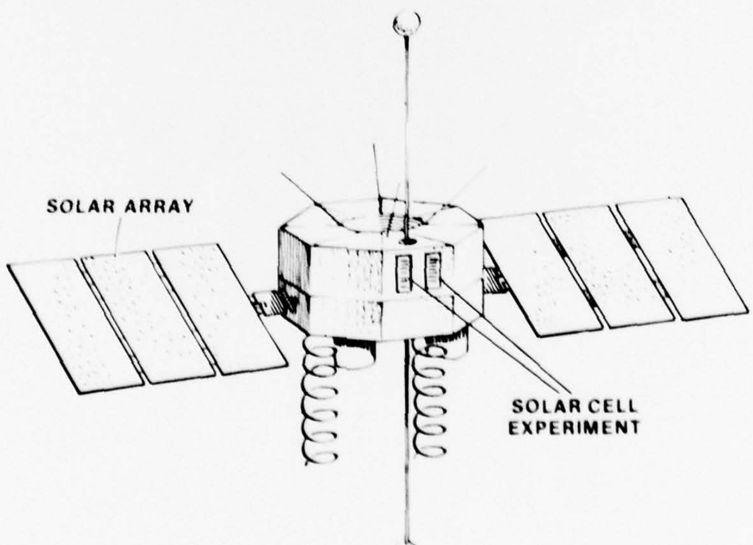

Fig. 1b - The NTS-2 satellite with solar arrays deployed and showing the location of the two solar cell experiment panels

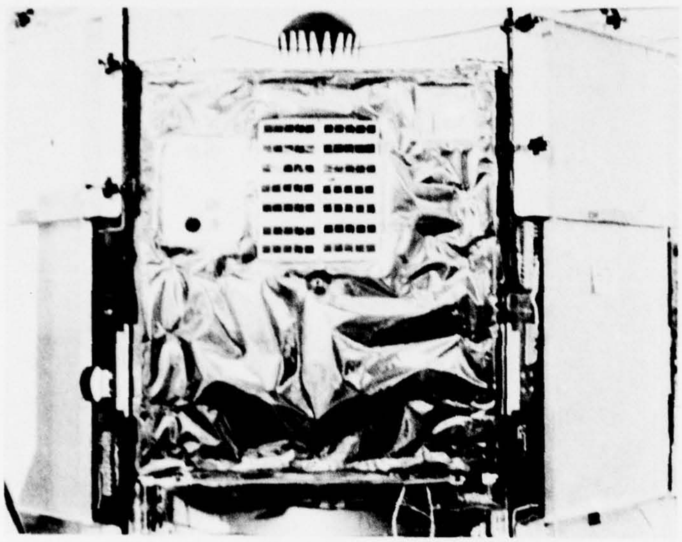

Fig. 2a - The NTS-2 solar cell experiments in place on the body of the satellite

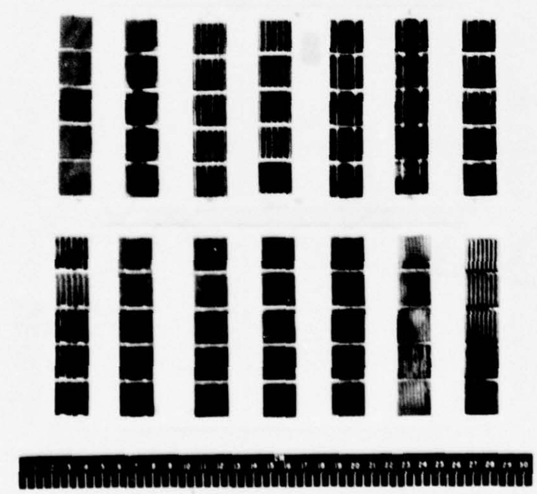

Fig. 2b - The NTS-2 14 five-cell module solar cell experiments as mounted on the flight panels

Table I — NTS-2 Solar Cell Experiments

Exp. No.	Cell Type	Thickness (cm)	Coverslip (cm)	Coverslip Bond (cm)	Interconnect	Efficiency 28°C (%)
1	OCLI Conventional, 2 ohm-cm	0.025	Corning 7940, AR and UV, (0.030)	R63-489	Cu/Ag	10.7
2	Spectrolab "Helios" p^+ 15-45 ohm-cm	0.0228	Ceria microsheet w/o AR, (0.025)	DC 93-500	Moly/Ag (.0025)	11.5
3	Spectrolab Hybrid Sculptured 7-14 ohm-cm	0.020	Corning 7940, AR and UV, (0.0152)	DC 93-500	Moly/Ag (.0025)	10.5
4	Spectrolab Hybrid Sculptured 7-14 ohm-cm	0.020	Corning 7940, w/o AR or UV, (0.0152)	FEP Teflon (0.0051)	Moly/Ag (.0025)	11.1
5	Comsat Non-Reflecting, p^+ Textured, 1.8 ohm-cm	0.025	Corning 7940, AR, w/o UV (.030)	R63-489	Ag, thermo-compression bonding	14.5
6	Comsat Non-Reflecting, p^+ Textured, 1.8 ohm-cm	0.025	Corning 7940, AR and UV (.030)	R63-489	Ag, thermo-compression bonding	14.6
7	Solarex Vertical Junction, p^+, 1.5 ohm-cm	0.030	Ceria microsheet w/o AR (.0152)	Sylgard 182	Ag mesh	13.0
8	Solarex Space Cell, p^+ 2 ohm-cm	0.025	Ceria microsheet w/o AR (0.0152)	Sylgard 182	Ag mesh	12.8
9	Spectrolab "Helios" p^+ Sculptured, BSR, 10 ohm-cm	0.030	Corning 7940 (.030) w/o AR or UV	FEP teflon (.003)	Ag mesh (.003)	14.2
10	OCLI Violet, 2 ohm-cm	0.025	Corning 7940 (.030) AR and UV	R63-489	Cu/Ag	13.5
11	Spectrolab P/N Li-doped 15-30 ohm-cm, Al contacts	0.020	Corning 7940, AR and UV, (0.015)	Silicone	Aluminum (.0025) Ultra-sonic welding	10.8
12	Spectrolab Planar Diode in series with Exp. 11	NA	NA	NA	NA	NA
13	OCLI Conventional, 2 ohm-cm	0.025	Corning 7070 (.028)	Electrostatic bonding	Cu/Ag	10.2
14	Spectrolab HESP, no p^+, Sculptured, 2 ohm-cm	0.030	Corning 7940, AR and UV (0.0305)	R63-489	Moly/Ag (.0025)	13.6
15	Hughes Gallium-Aluminum Arsenide	0.0305	Corning 7940, AR and UV, (0.0305)	DC 93-500	Aluminum GPD (.0025), epoxy	13.6

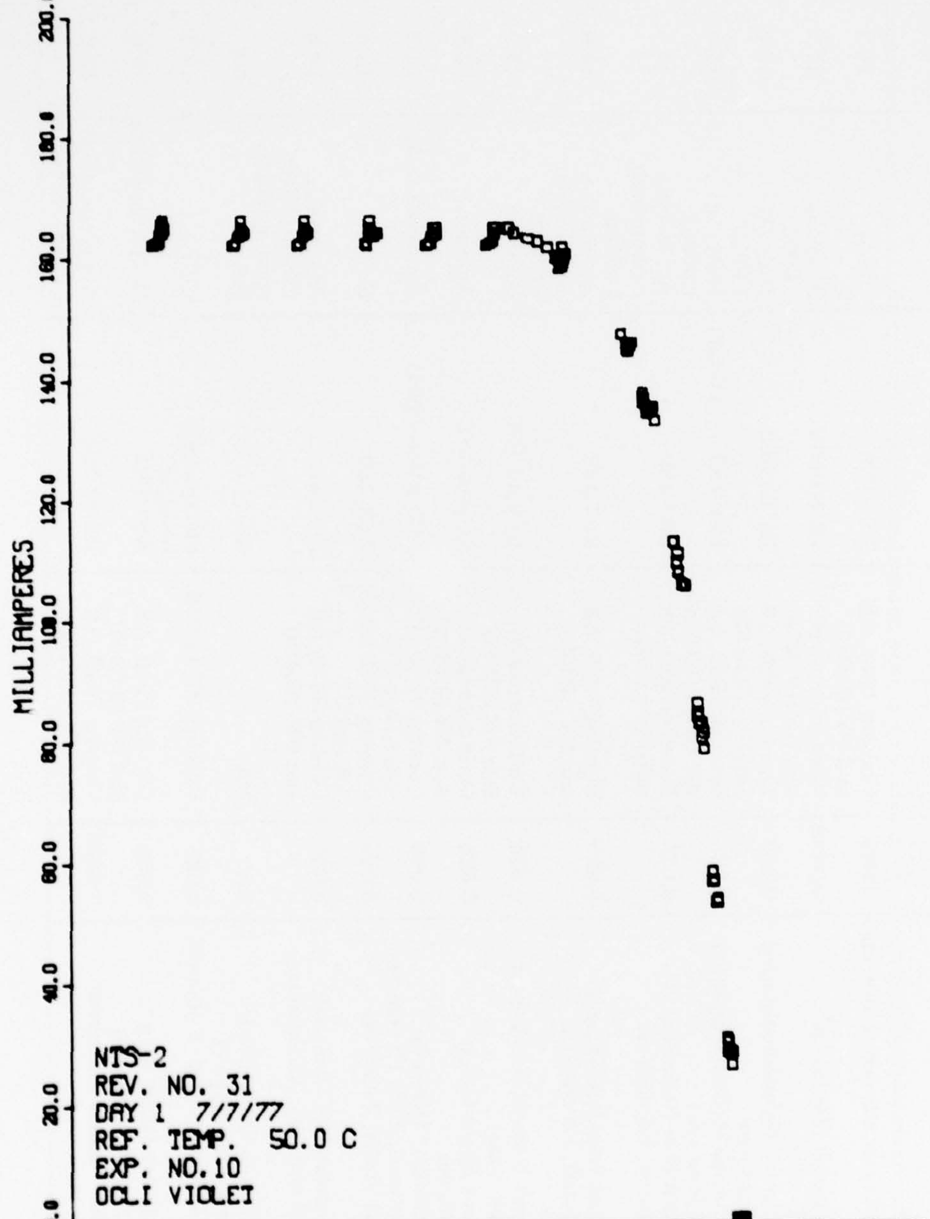

Fig. 3 - A typical current-voltage data curve as received from the NTS-2 satellite, corrected for solar intensity, sun angle and to a temperature of 50°C

Table II — NTS-2 Short-Circuit Current Output for Solar Cell Experiments
Short-Circuit Current Output (mA/4 cm^2)*

Experiment No.	Cell Type	Solar Simulator	Day 1 in Orbit
1	OCLI Conv. 2 ohm-cm	135.4	136.5
2	Spectrolab Helios (NTS-2)	154.5	155.5
3	Spectrolab Text. Hybr., F.S.	155.6	154.0
4	Spectrolab Text. Hybr., FEP, F.S. w/o filter	151.0	149.6
5	Comsat Text. F.S., w/o filter	184.8	180.4
6	Comsat Text. F.S.	180.8	178.7
7	Solarex Vert. Junc.	158.4	160.5
8	Solarex Space Cell	155.9	158.8
9	Spectrolab Text. Helios Reflector	174.3	175.8
10	OCLI Violet, F.S.	165.1	164.3
11	Spectrolab HASP w/o diode	136.2	132.6
12	Spectrolab HASP w/diode	134.5	132.4
13	OCLI Conv., ESB	147.3	146.1
14	Spectrolab HESP	166.2	165.8
15	HRL AlGaAs	102.9	100.6

*These data have been corrected to 50°C at one-sun and air mass zero (AMO).

Table III — NTS-2 Open-Circuit Voltage Output for Solar Cell Experiments*

Experiment No.	Cell Type	Solar Simulator	Day 1 in Orbit
1	OCLI Conv. 2 ohm-cm	533	549
2	Spectrolab Helios (NTS-2)	527	546
3	Spectrolab Text. Hybr., F.S.	491	508
4	Spectrolab Text. Hybr., FEP, F.S. w/o filter	491	505
5	Comsat Text. F.S., w/o filter	533	555
6	Comsat Text. F.S.	533	549
7	Solarex Vert. Junc.	528	521
8	Solarex Space Cell	535	541
9	Spectrolab Text. Helios Reflector	550	545
10	OCLI Violet, F.S.	550	552
11	Spectrolab HASP w/o diode	552	559
12	Spectrolab HASP w/diode	523	523
13	OCLI Conv., ESB	488	490
14	Spectrolab HESP	533	528
15	HRL AlGaAs	914	895

*These data have been corrected to 50°C at one-sun and air mass zero (AMO).

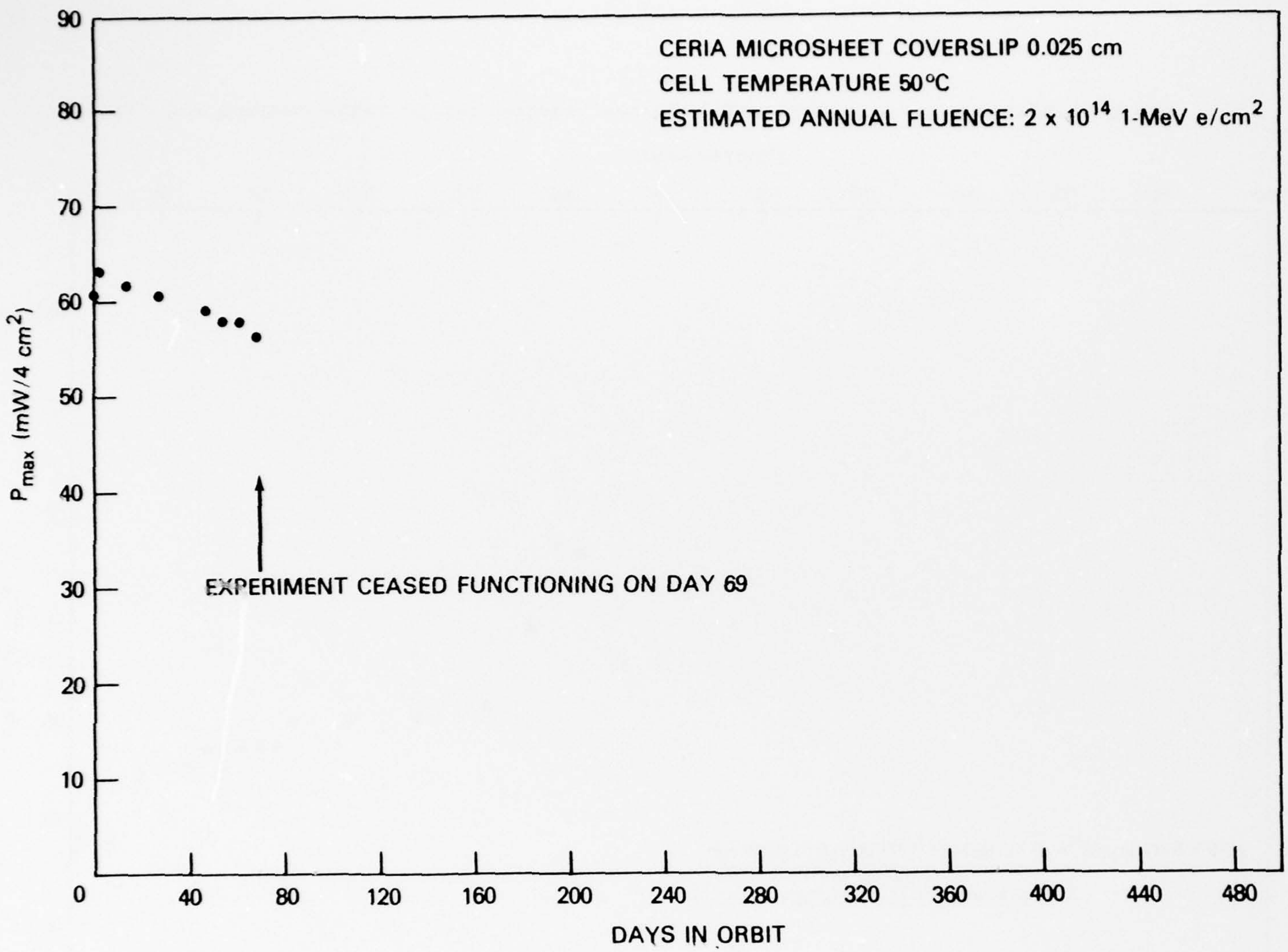

Fig. 4 - Maximum power degradation of the Solarex "low-cost space cell" normalized to 4 cm^2

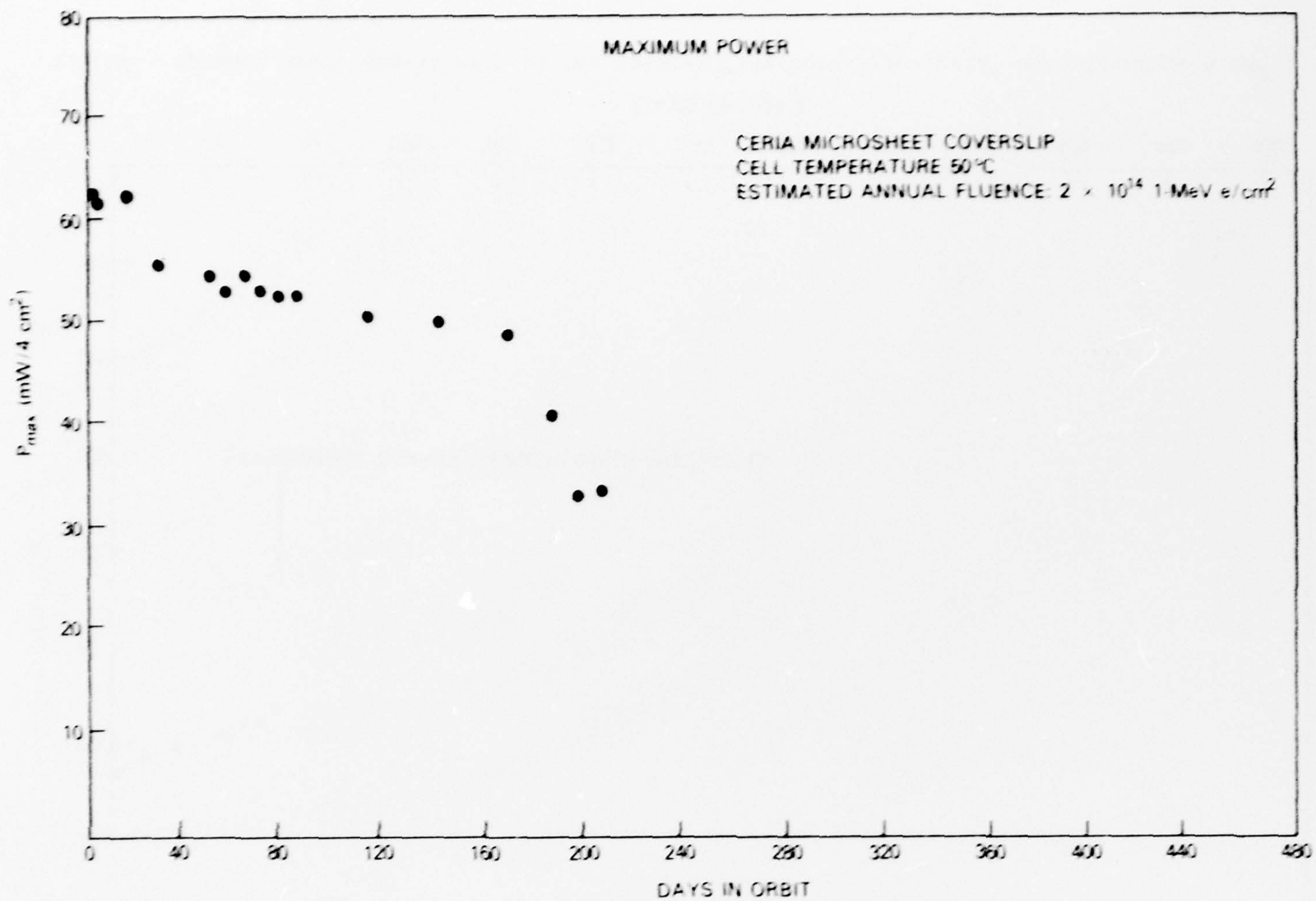

Fig. 5 - Maximum power of the Solarex vertical junction cell, normalized to 4 cm^2

After 223 days in orbit, the other solar cell experiments continue to generally function well. Among the experiments of primary interest is the Spectrolab "Helios" cell. This cell was space qualified as one of the experiments aboard the NTS-1 satellite. The "Helios" cell is presently in use as the main power source on NTS-2 and is in use in other satellite programs. As of day 223, the maximum power output of the Spectrolab Helios cell (NTS-2) has decreased by 12.7 percent. The maximum power versus days in orbit for this experiment is shown in Fig. 6.

The gallium arsenide cell is a high-efficiency solar cell that is expected to be radiation hardened and therefore quite durable for space applications. The problems of surface recombination and low lifetime in the diffused region are largely overcome by the addition of a GaAlAs window. An array made up of Hughes Research Laboratory's gallium arsenide (GaAlAs/GaAs) solar cells comprises Experiment #15 on NTS-2.

As shown in Fig. 7, the initial degradation in the gallium arsenide cells was observed to begin to anneal after 28 days in orbit and continued until about day 80. The annealing mechanism may be operating to some extent as radiation damage accumulates in the cell. This may explain why the gallium arsenide cell degrades at a slower rate than the other types of cells. Although the gallium arsenide cell was not the cell with the highest BOL power (see Table IV), if the present relative degradation rate continues, the GaAs cell may have the highest end-of-life power after 3 years. At present its maximum power output has decreased to 58.6 mW, a decrease of only 4.6 percent. The maximum power of the gallium arsenide cell versus days in orbit is shown in Fig. 7. During the mission, the maximum temperature of the solar cell panel has gradually increased from 71.5°C on day 28, when evidence of annealing began, to 101.4°C on day 223. The average temperatures of the two solar cell panels versus days in orbit is given in Fig. 8.

The Comsat textured cell was flown with and without an ultraviolet rejection filter in order to evaluate the effect of the filter. Figure 9 shows the degradation of the Comsat textured cell in both configurations. Although the two arrays start with approximately the same beginning-of-life short-circuit current, the I_{sc} of the cells with the uv filter (Experiment #6) degraded only 9.1 percent. However, the I_{sc} of Experiment #5 without the uv filter is down by 30.6 percent. This amount is much greater than was expected solely from the absence of the uv filter. There may be another degradation factor involved which is so far unexplained. Laboratory experiments indicate that solar cell degradation from ultraviolet light is of the order of 2 to 4 percent. The damage occurs during

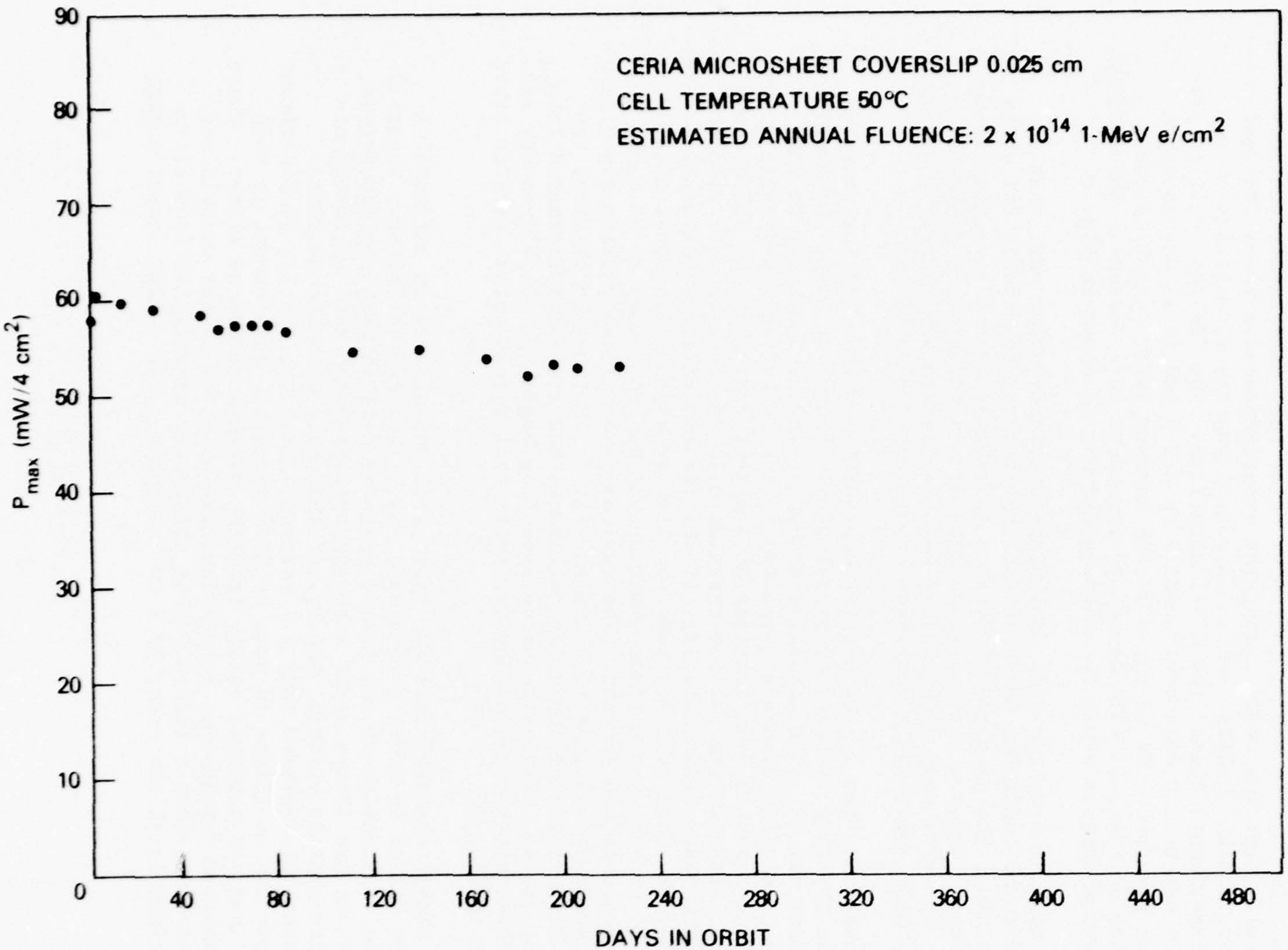

Fig. 6 - Maximum power degradation of the Spectrolab Helios cell normalized to 4 cm^2

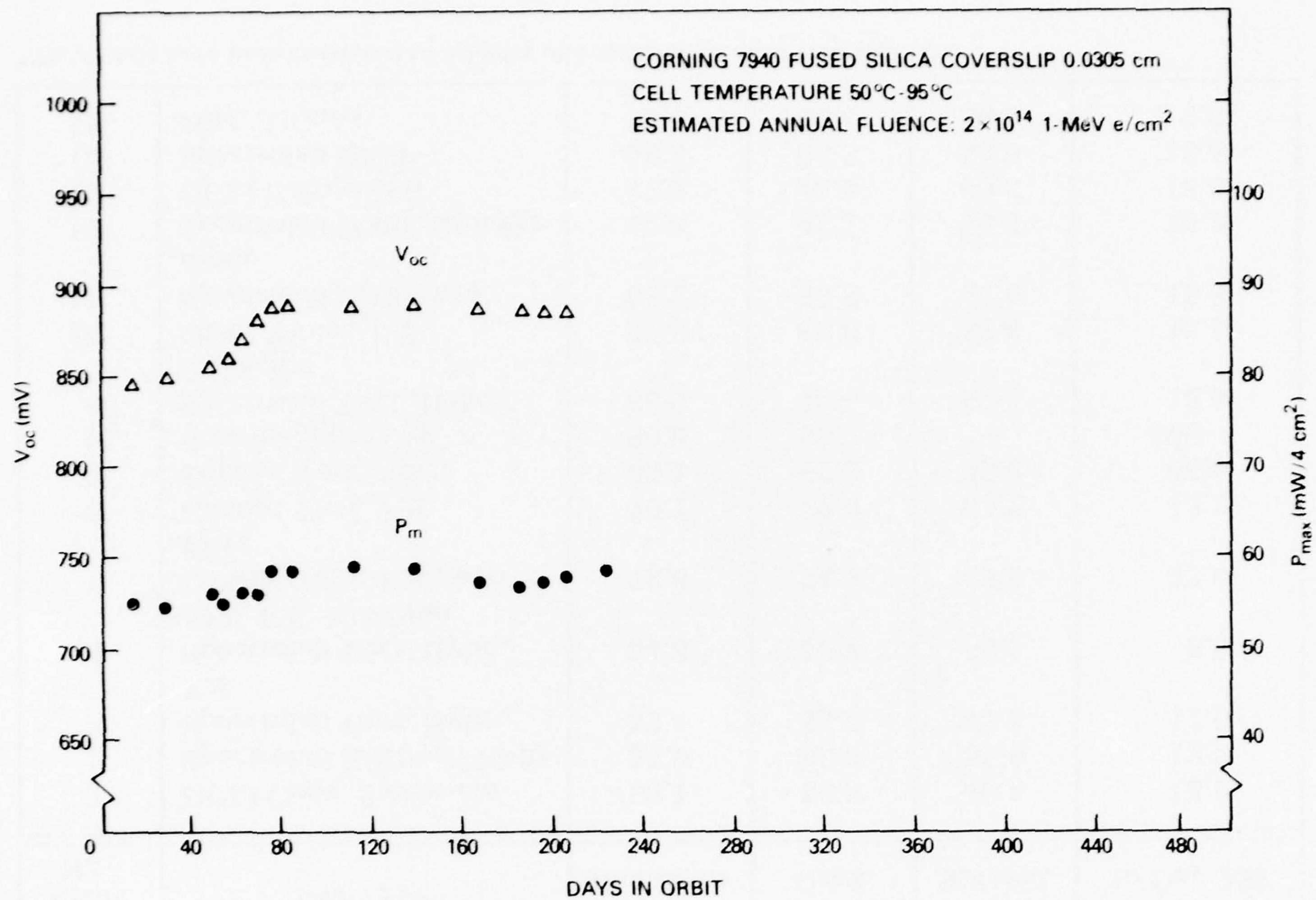

Fig. 7 - Maximum power and open-circuit voltage degradation of the Hughes gallium arsenide cell. P_{max} is normalized to 4 cm^2.

Table IV — NTS-2 Maximum Power Output for Solar Cell Experiments
Maximum Power Output (mW/4 cm^2)*

Experiment No.	Cell Type	Solar Simulator	Day 1 in Orbit	Day 223 in Orbit	% Loss Day 1 to Day 223
1	OCLI Conv. 2 ohm-cm	53.1	56.3	48.5	13.9
2	Spectrolab Helios (NTS-2)	57.9	60.6	52.9	12.7
3	Spectrolab Text. Hybr., F.S.	52.4	53.5	47.6	11.0
4	Spectrolab Text. Hybr., FEP, F.S. w/o filter	54.6	55.4	50.5	8.8
5	Comsat Text. F.S., w/o filter	72.8	74.7	49.6	33.6
6	Comsat Text. F.S.	70.1	72.0	63.2	12.2
7	Solarex Vert. Junc.	63.1	62.2	33.3	46.5
8	Solarex Space Cell	60.6	63.1	—	100
9	Spectrolab Text. Helios Reflector	66.0	70.0	60.5	13.6
10	OCLI Violet, F.S.	67.5	66.6	57.6	13.5
11	Spectrolab HASP w/o diode	53.2	55.8	47.0	15.8
12	Spectrolab HASP w/diode	42.0	42.1	35.3	16.2
13	OCLI Conv., ESB	47.0	46.8	40.3	13.9
14	Spectrolab HESP	63.3	63.8	53.9	15.5
15	HRL AlGaAs	70.0	61.4	58.6	4.6

*These data have been corrected to 50°C at one-sun and air mass zero (AMO).

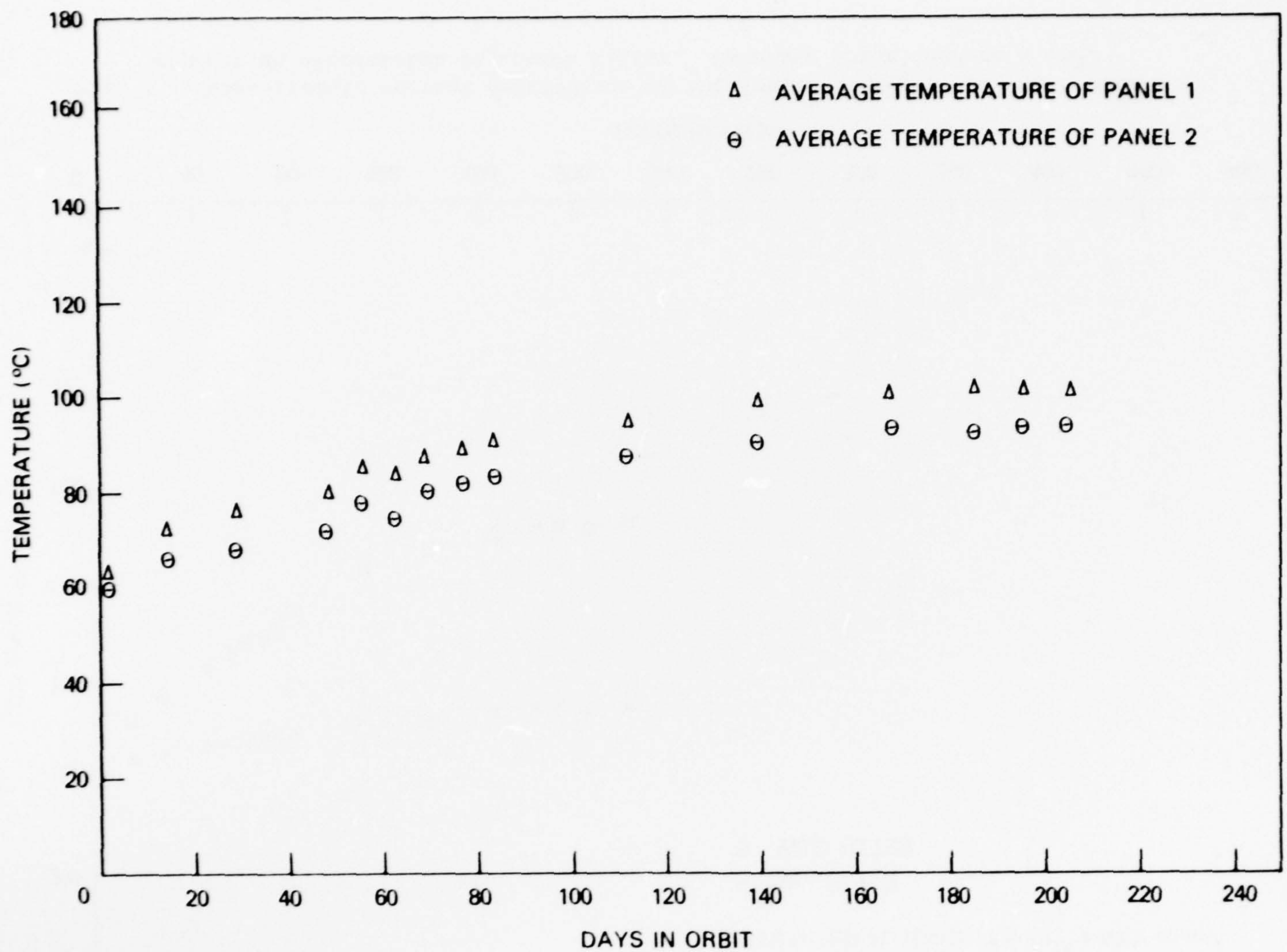

Fig. 8 - The average temperature of the solar cell panels over the first 233 days in orbit

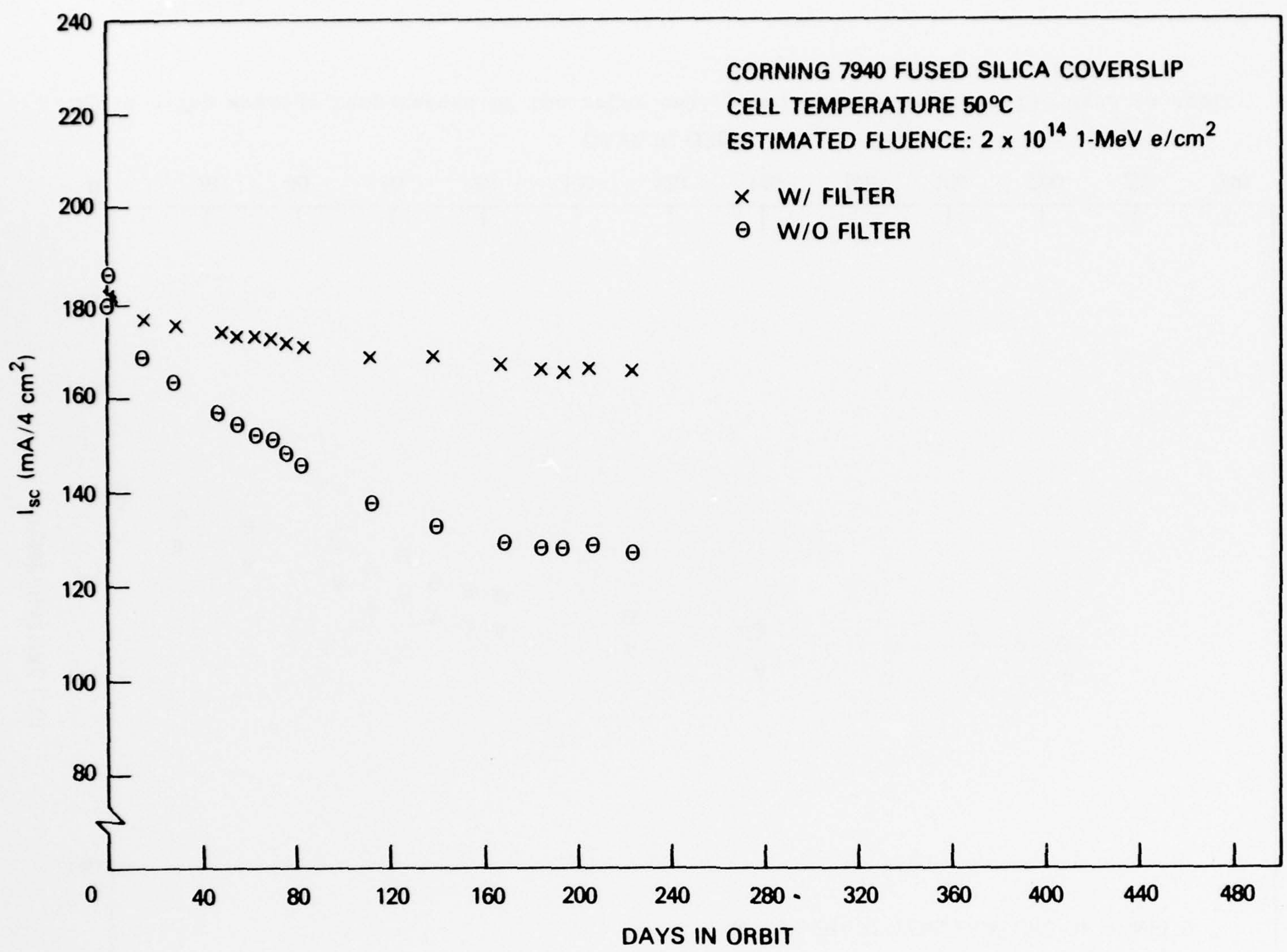

Fig. 9 - Short-circuit current degradation of the Comsat textured cell both with and without an ultraviolet rejection filter. Data are normalized to 4 cm^2.

the first few days or weeks due to darkening of the adhesive. Perhaps the laboratory experiments were not extended long enough or perhaps there is some defect in the adhesive used in this case. If the degradation seen in the I_{sc} of these cells were caused by particle radiation in the cell, the V_{oc} would be severely degraded. Figure 10 shows that the V_{oc} of the cells with and without uv filter is essentially the same, and the fill factor of Experiment #5 is also unaffected. The knee of the I-V curve would be noticably "softened" if the cells had suffered radiation damage.

Experiments #3 and #4 compare the effects of removing the ultraviolet rejection filter from the Spectrolab textured hybrid cell. The coverslide in Experiment #4, the one without the uv filter, is bonded with FEP Teflon. Since there is no adhesive to darken, the absence of a uv filter should have no effect. The data presented in Fig. 11 indicate that there is little difference. The experiments began with a BOL maximum power of 53.5 mW and 55.4 mW, respectively. At present, the P_{max} of #3 with a uv filter is down to 47.5 mW (11.0 percent) and #4 without a uv filter is down to 50.5 mW or 8.8 percent.

The percent losses in the photovoltaic parameters of all the experiments may be compared in Table V.

Prior to launch, it was estimated that the trapped radiation fluence of electrons and protons in NTS-2's twelve-hour 63 degree orbit would be equivalent to 2×10^{14} 1-MeV electrons/cm^2-year. The effect of the natural trapped radiation environment was calculated from data available from the National Space Science Data Center, NASA.[15,16] Computerized calculations were made of solar cell I-V curves as a function of temperature and coverslip thickness, using a program developed for NASA Goddard Space Flight Center.[17] In this environment the solar cells in the power paddles, consisting of Spectrolab Helios cells covered with 0.025 cm ceria microsheet, would lose 26 percent in maximum power over the satellite-design life of three years.

The solar cell experiments have been in orbit a sufficiently long time to experience enough radiation damage to allow one to make predictions of future damage rates. The fluence of equivalent 1-MeV electrons/cm^2 experienced by four (4) selected groups of solar cells by day 200 is tabulated in Table VI. The corrected space data for these experiments are shown in Figs. 12-15. The experimental results from these experiments

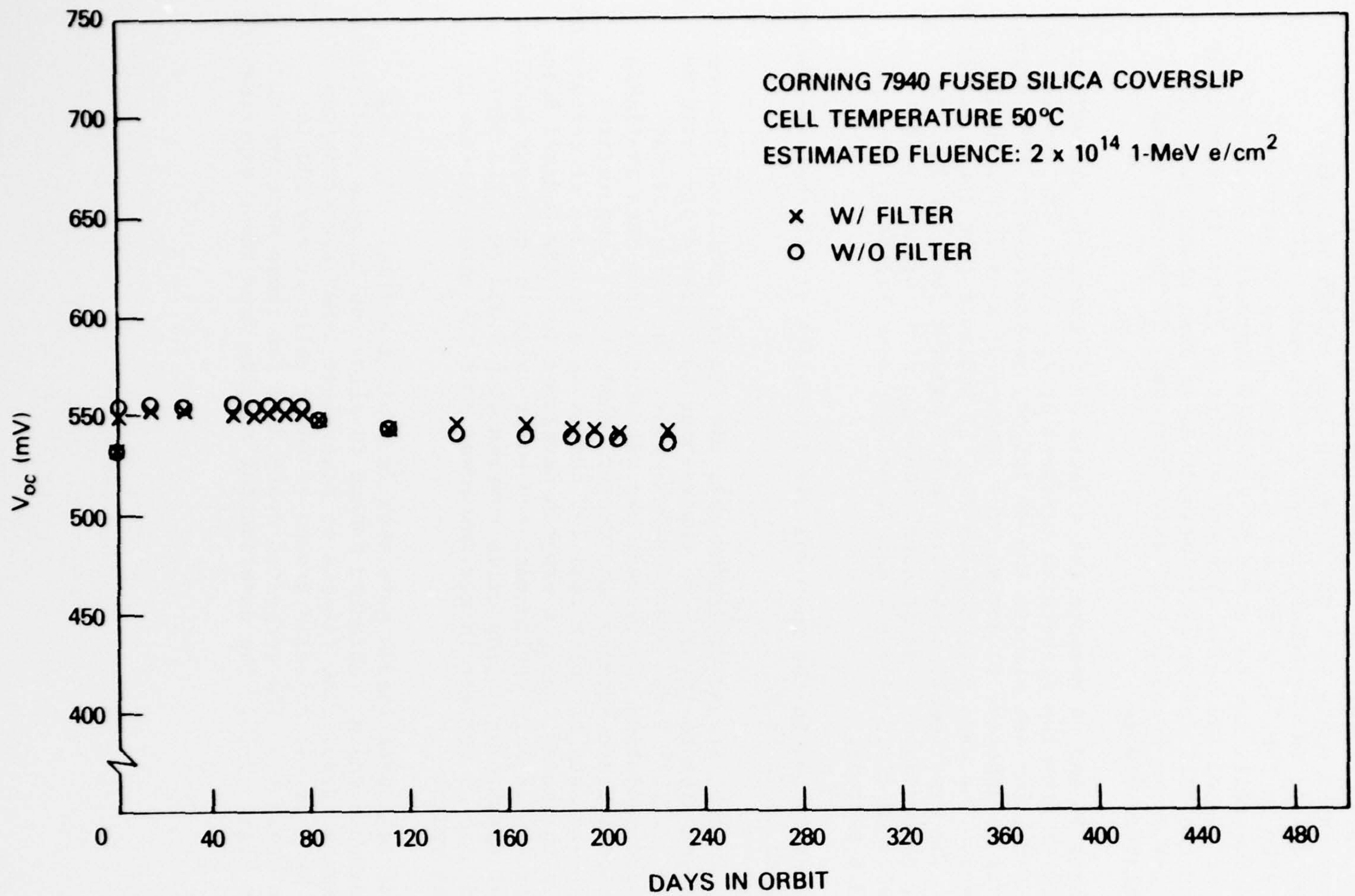

Fig. 10 - Open-circuit voltage degradation of the Comsat textured cell both with and without an ultraviolet rejection filter.

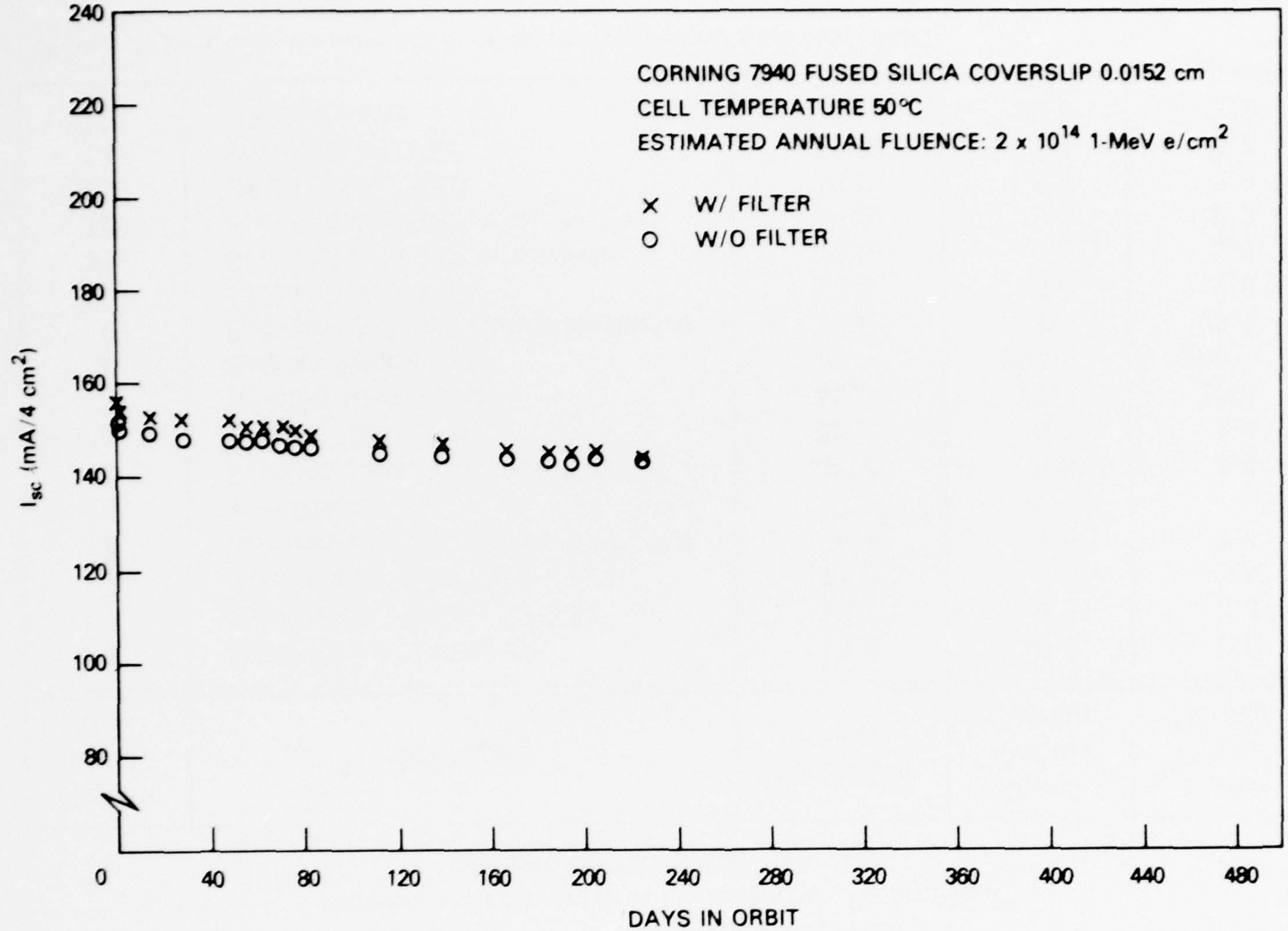

Fig. 11 - Short-circuit current of the Spectrolab textured hybrid cell both with and without an ultraviolet rejection filter. Data normalized to 4 cm^2.

Table V — NTS-2 Solar Cell Experiments
Summary of Changes in Photovoltaic Parameters*
Percent Loss Day 1 to Day 223

Experiment No.	Cell Type	Maxi[illegible]m Po[illegible]	Short-Circuit Current	Open-Circuit Voltage
1	OCLI Conv. 2 ohm-cm	[illegible]	10.4	0.9
2	Spectrolab Helios (NTS-2)	12.7	6.6	3.3
3	Spectrolab Text. Hybr., F.S.	11.0	7.0	1.4
4	Spectrolab Text. Hybr., FEP, F.S. w/o filter	8.8	4.5	1.4
5	Comsat Text. F.S., w/o filter	33.6	30.6	3.4
6	Comsat Text. F.S.	12.2	8.1	1.6
7	Solarex Vert. Junc.	46.5	16.8	18.4
8	Solarex Space Cell	100	100	100
9	Spectrolab Text. Helios Reflector	13.6	7.1	3.5
10	OCLI Violet, F.S.	13.5	10.0	1.6
11	Spectrolab HASP w/o diode	15.8	10.0	2.5
12	Spectrolab HASP w/diode	16.2	9.9	2.3
13	OCLI Conv., ESB	13.9	6.6	3.9
14	Spectrolab HESP	15.5	7.4	5.1
15	HRL AlGaAs	4.6	12.3	1.2

*These data have been corrected to 50°C at one-sun and air mass zero (AMO).

Table VI — NTS-2 Equivalent Fluence (1 - MeV e/cm^2) Predictions*

OCLI Conventional 2 Ω-cm, 10 mil cell, 12 mil FS Coverslip

	BOL	Fluence at 200 days	Fluence at 1 yr	Fluence at 3 yr
I_{sc}	136.0 mA	1.5×10^{14}	2.7×10^{14}	8.2×10^{14}
V_{oc}	548 mV	3×10^{13}	5.5×10^{13}	1.6×10^{14}
P_m	56.5 mW/4 cm^2	1.3×10^{14}	2.4×10^{14}	7.1×10^{14}
Spectrolab Helios, 10 Ω-cm, 9 mil cell, 10 mil Ceria Coverslip				
	BOL	Fluence at 200 days	Fluence at 1 yr	Fluence at 3 yr
I_{sc}	154 mA	1.3×10^{14}	2.4×10^{14}	7.1×10^{14}
V_{oc}	545 mV	1×10^{13}	1.8×10^{13}	5.5×10^{13}
P_m	60.5 mW/4 cm^2	9×10^{13}	1.6×10^{14}	4.9×10^{14}
Spectrolab Textured Hybrid, 8 mil cell, 6 mil FS Coverslip				
	BOL	Fluence at 200 days	Fluence at 1 yr	Fluence at 3 yr
I_{sc}	156 mA	5.0×10^{14}	9.1×10^{14}	2.7×10^{15}
V_{oc}	522 mV	5.0×10^{14}	9.1×10^{14}	2.7×10^{15}
P_m	53.8 mW/4 cm^2	3.3×10^{14}	6.0×10^{14}	1.8×10^{15}
OCLI Violet				
	BOL	Fluence at 200 days	Fluence at 1 yr	Fluence at 3 yr
I_{sc}	166 mA	1×10^{13}	1.8×10^{14}	5.5×10^{14}
V_{oc}	552 mV	2×10^{13}	3.7×10^{13}	1.1×10^{14}
P_m	67.5 mW/4 cm^2	7.5×10^{13}	1.4×10^{14}	4.1×10^{14}

*Cell data at 50°C

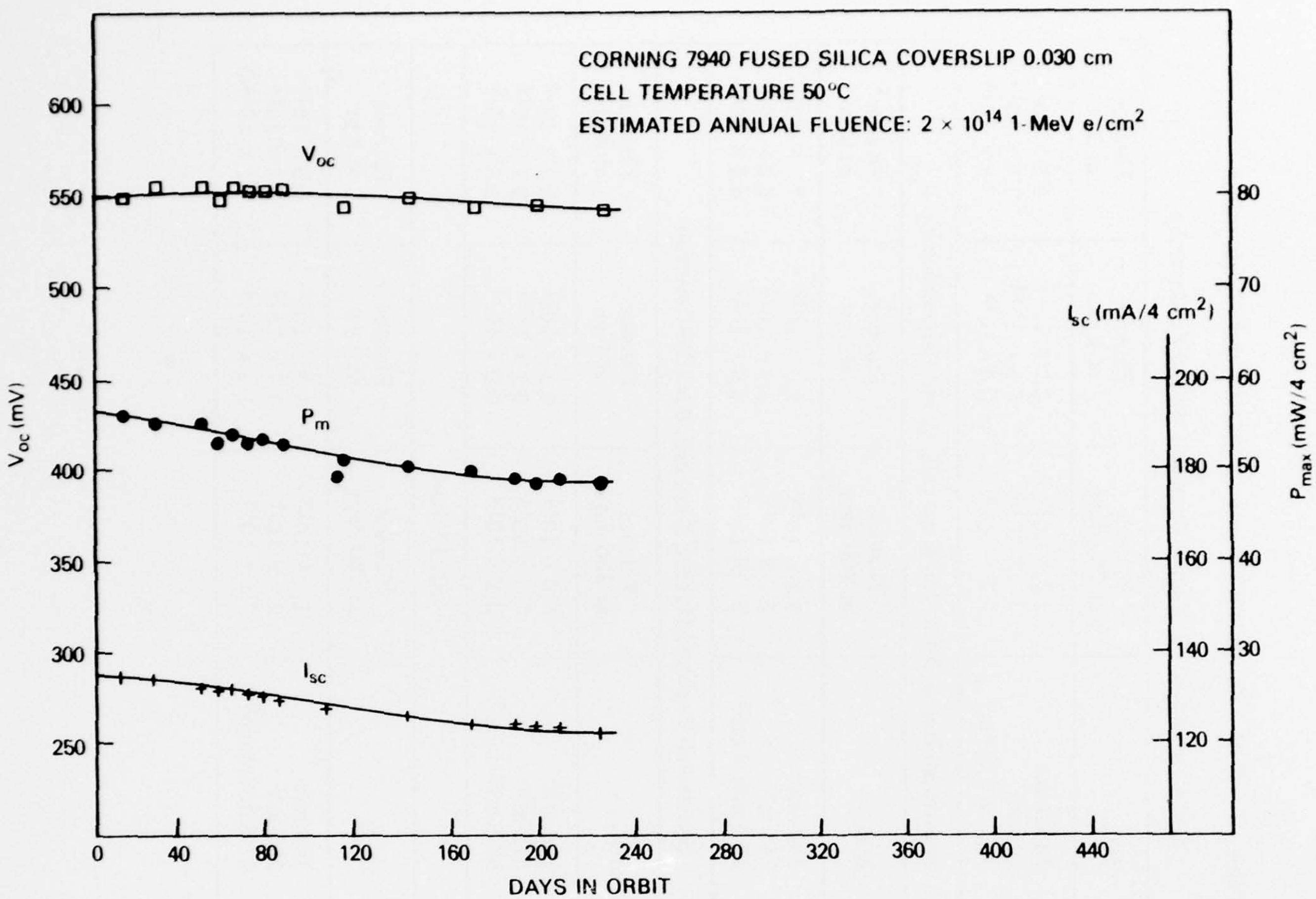

Fig. 12 - Degradation of V_{oc}, P_m and I_{sc} for the OCLI 2 ohm-cm cells

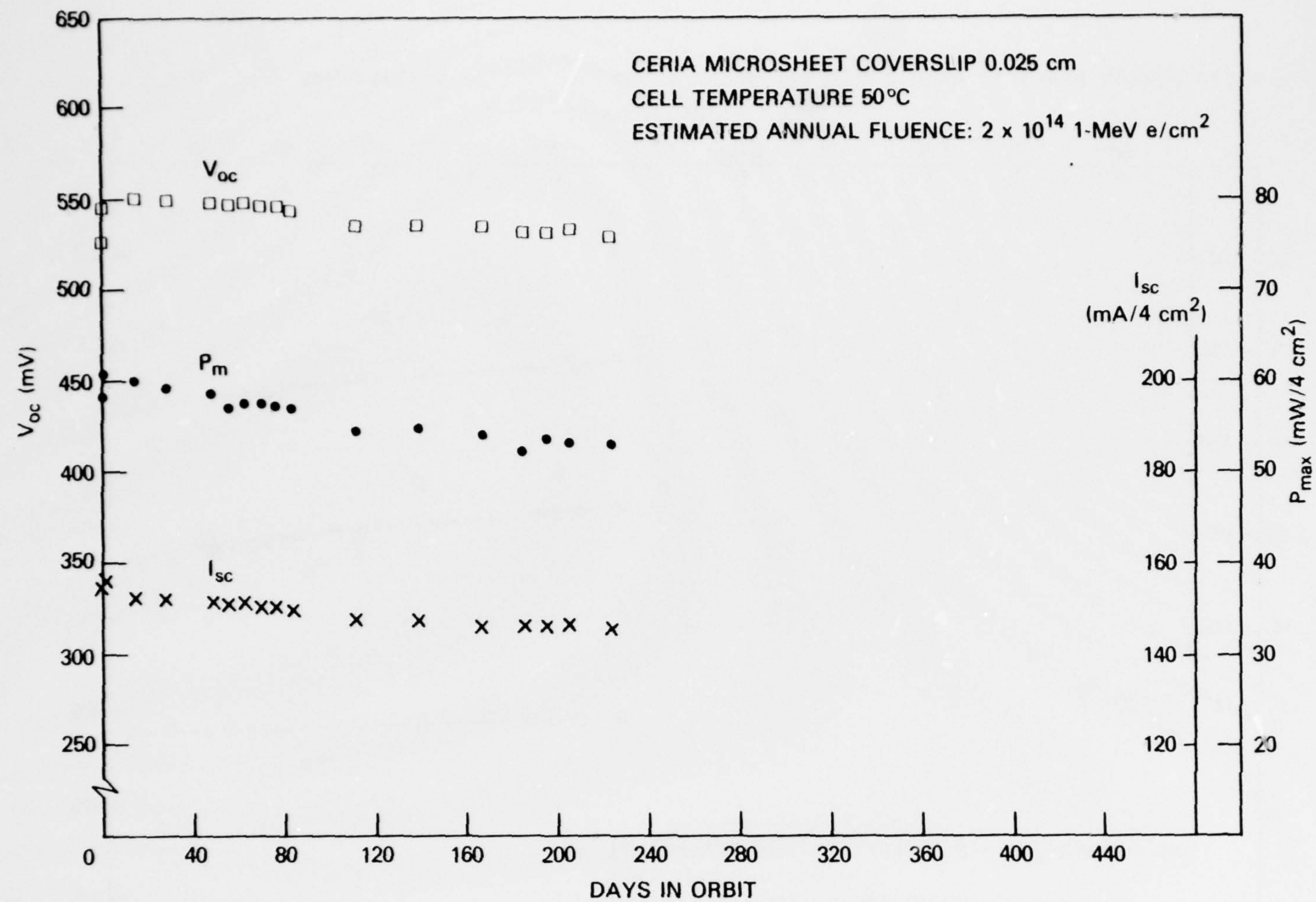

Fig. 13 - Degradation of V_{oc}, P_m and I_{sc} for the spectrolab Helios cells

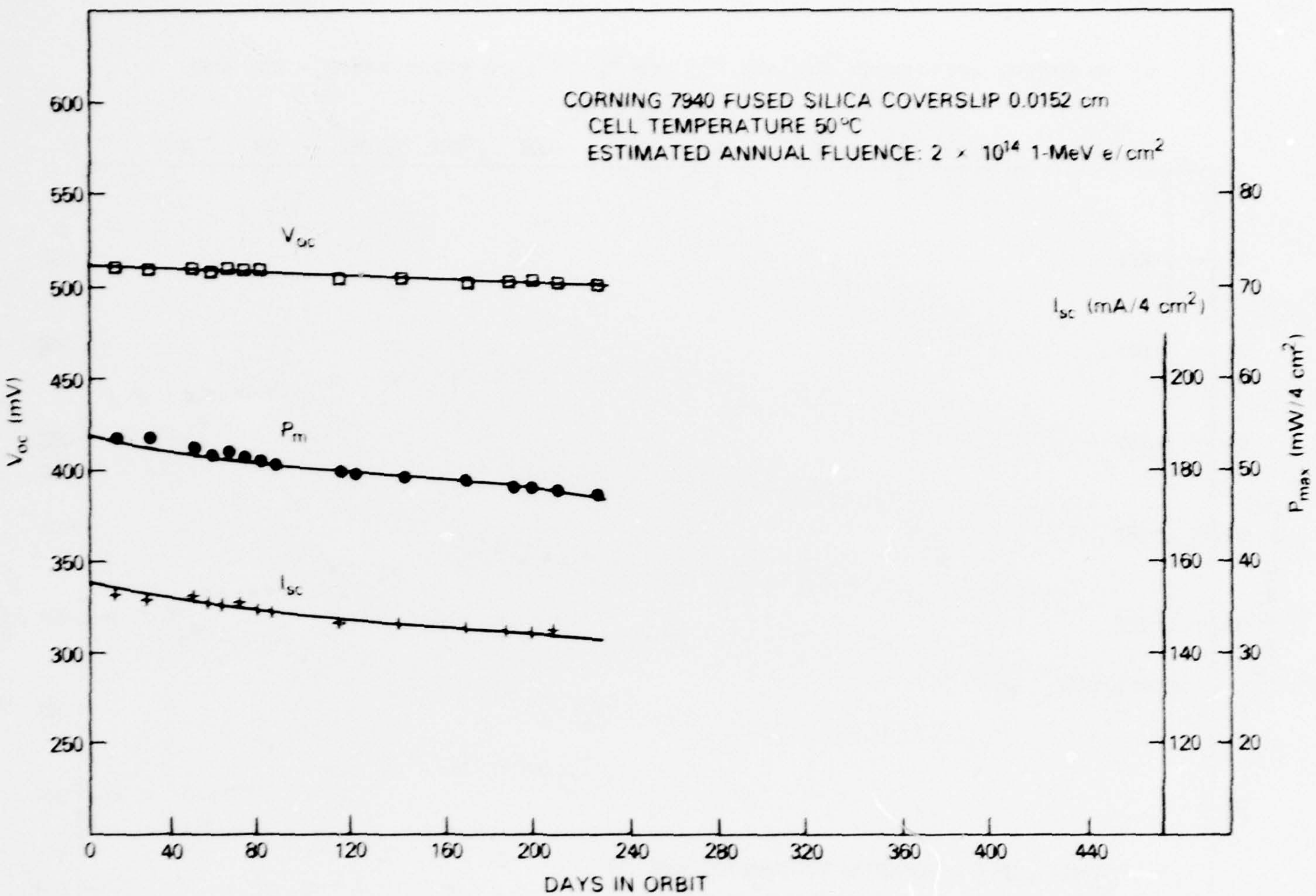

Fig. 14 - Degradation of V_{oc}, P_m and I_{sc} for the Spectrolab textured hybrid cells

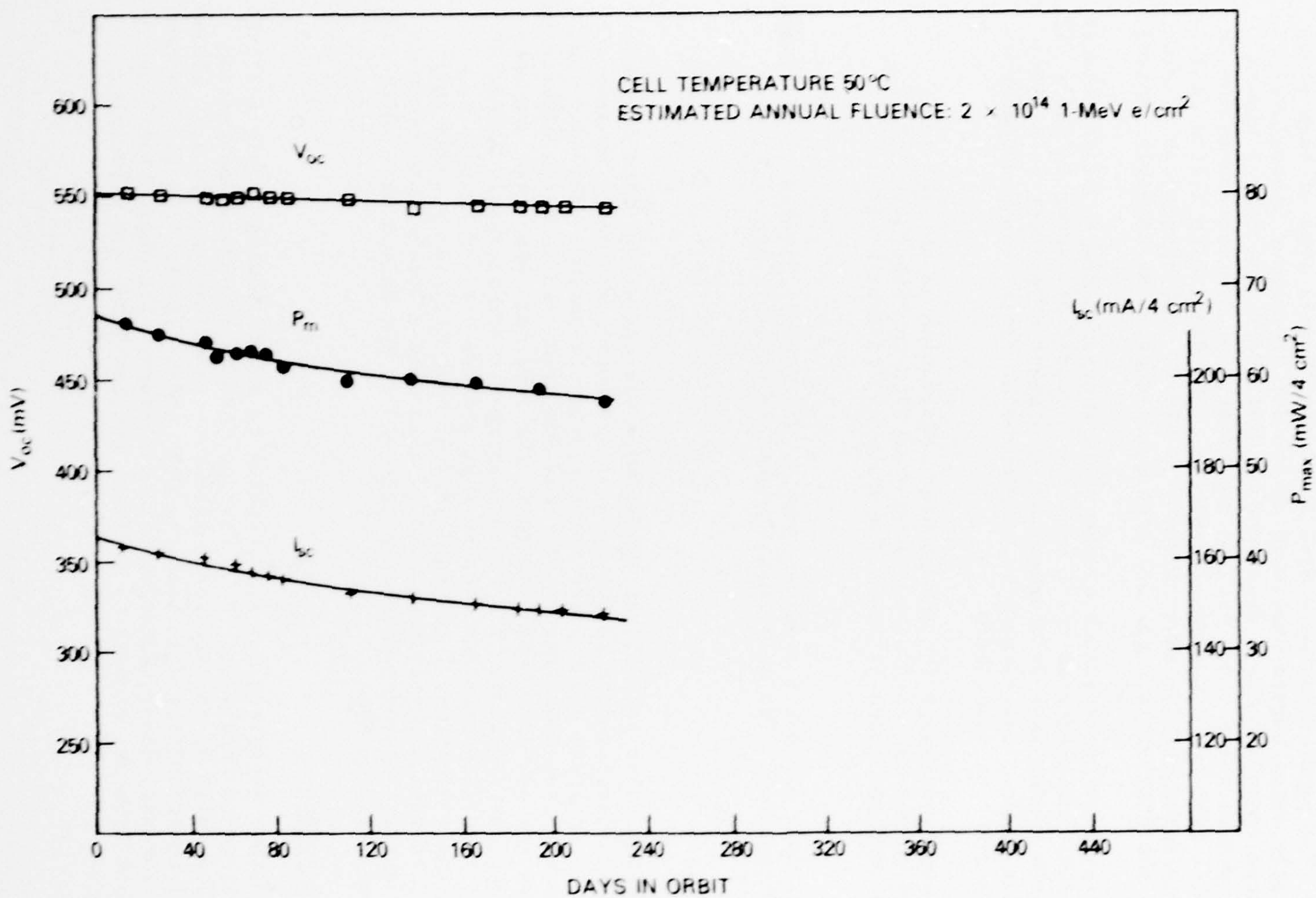

Fig. 15 - Degradation of V_{oc}, P_m and I_{sc} for the OCLI violet cells

indicate a more severe radiation environment than predicted. These data were used to predict the estimated annual fluence and the fluence over 3 years. The predictions were made according to cell type of each group individually using curves published by the Jet Propulsion Laboratory[18] and updated computer models developed by NASA.[19,20] The OCLI 2 ohm-cm cell is used as a reference because the effects of electron radiation on these cells have been studied extensively. The Spectrolab Helios cell is being considered for the power system for NTS-3. The Spectrolab hybrid cell and the OCLI violet cell are also being studied as possible choices.

The relative degradations of the cells mentioned above, as calculated for day 200, and predicted for 1 year and 3 years, are shown in Table VII. It is worth noting that Goldhammer in the present experiment on ATS-6[21] observed a greater cell damage in a synchronous orbit than had been predicted by previous experience.

Although the reason for the greater degradation is not yet fully explained in our case it may be associated with the inadequacy of existing computer codes to model the space environment as it actually exists.

Solar data are being recorded weekly, and monthly updates of processed data are prepared. The experimental panel temperature has stabilized near 100°C.

Conclusions

The NTS-2 solar cell flight experiments are operating quite successfully. Good quality data in the form of I-V curves are being received. The results indicate areas where further study is needed. The fact that a more severe radiation environment than was predicted is being experienced emphasizes the need for improvements in the computer codes that are used to make such predictions. The NTS-2 experiments are extremely important to future satellite programs because they provide the opportunity to continue the evaluation of several types of high efficiency solar cells in a hard radiation environment, and to also make a direct comparison to a flight-quality conventional solar cell and to the Helios cell which was flight qualified on NTS-1.

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Table VII — Percent of I_{sc}, V_{oc} and P_{max} Remaining after 200 Days in Orbit and Predictions for Percent Remaining at 1 yr and 3 yrs*

OCLI Conventional, 2 Ω-cm, 10 mil cell, 12 mil FS Coverslip

	BOL	Relative Degradation at 200 days	Relative Degradation at 1 yr	Relative Degradation at 3 yrs
I_{sc}	136.0 mA	.91	.87	.81
V_{oc}	548 mV	.98	.97	.94
P_m	56.5 mW/4 cm^2	.87	.82	.75
Spectrolab Helios, 10 Ω-cm, 9 mil cell, 10 mil Ceria Coverslip				
	BOL	Relative Degradation at 200 days	Relative Degradation at 1 yr	Relative Degradation at 3 yrs
I_{sc}	154 mA	.95	.91	.87
V_{oc}	545 mV	.98	.96	.93
P_m	60.5 mW/4 cm^2	.88	.84	.76
Spectrolab Textured Hybrid, 8 mil cell, 6 mil FS Coverslip				
	BOL	Relative Degradation at 200 days	Relative Degradation at 1 yr	Relative Degradation at 3 yrs
I_{sc}	156 mA	.93	.90	.82
V_{oc}	522 mV	.96	.94	.90
P_m	53.8 mW/4 cm^2	.90	.87	.74
OCLI Violet, 10 mil cell, 12 mil FS Coverslip				
	BOL	Relative Degradation at 200 days	Relative Degradation at 1 yr	Relative Degradation at 3 yrs
I_{sc}	166 mA	.90	.84	.80
V_{oc}	552 mV	.98	.97	.95
P_m	67.5 mW/4 cm^2	.87	.83	.75

*Cell data at 50°C

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